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ALKALINE CYANIDE LEACHING OF BELMORAL CONCENTRATE

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K.E. Haque* and M.R. Rumfeldt**

ABSTRACT

Alkaline cyanide leaching of the Belmoral concentrate provided 95-98% gold extraction with only 24 hours of cyanidation when the leach slurries were preoxidized with air, oxygen, ozone, H_2O_2 , $Pb(NO_3)_2$ or Pb_3O_4 . However, without such a preoxidation, at least 72 hours of cyanidation is required to obtain a minimum of 97% gold extraction. Therefore, reduction of cyanidation time to 24-48 hours from the current 72-150 hours could be accomplished by preoxidation of the leach slurries.

Keywords: Belmoral concentrate, leaching of Belmoral concentrate, preoxidation, cyanidation of gold concentrate, gold leaching, concentrate leaching

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LIXIVIATION ALCALINE PAR CYANURATION DU CONCENTRÉ BELMORAL

par

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RÉSUMÉ

La lixiviation alcaline par cyanuration du concentré Belmoral a permis de récupérer de 95 à 98 % du contenu aurifère. La cyanuration a été réalisée en 24 heures seulement, période pendant laquelle les bouillies de lixiviation ont été préoxydées avec de l'air, de l'oxygène, de l'ozone, H_2O_2 , $Pb(NO_3)_2$ ou Pb_3O_4 . Cependant, pour récupérer une quantité minimale de 97 % du contenu aurifère, la cyanuration sans préoxydation exige une période d'au moins 72 heures. Par conséquent, la réduction de la période de cyanuration qui prend, à l'heure actuelle, de 72-150 heures à 24-48 heures, pourrait être réalisée par la préoxydation des bouillies de lixiviation.

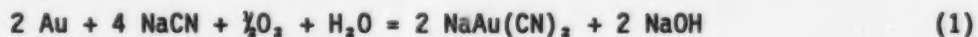
Mots-clé : concentré Belmoral, lixiviation du concentré Belmoral, préoxydation, cyanuration du concentré aurifère, lixiviation de l'or, lixiviation du concentré

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INTRODUCTION

The alkaline cyanidation process has been used commercially for almost 100 years in the treatment of gold ores. Chemically, cyanide anion (CN^-) reacts with gold cation (Au^+) and forms a water soluble aurocyano complex $[\text{Au}(\text{CN})_2]^-$ (eq. 1).



The presence of oxygen or an oxidant in the leach slurry is essential for the oxidation of neutral gold (Au^0) into gold cation (Au^+). Without this oxidation, aurocyano complex formation cannot take place. Furthermore, maximum cyanide anion (CN^-) concentration occurs at pH values above 9.5. Because of this, gold cyanidation generally is conducted at a pH of 10-11 with a water soluble cyanide of alkali or alkaline earth metal in a leach slurry previously preaerated with air or oxygen. However, only free milling gold ore or concentrate (i.e., when gold grains are not physically or chemically bound with other mineral matrices) is amenable to the alkaline cyanidation process.

When gold is bound with sulphides, arsenides, tellurides or carbonaceous material, gold recovery by the alkaline cyanidation process becomes uneconomical (both in terms of recovery and cyanide consumption). This type of gold ore or concentrate is designated as refractory gold ore. Under these circumstances, gold is first liberated from the mineral matrix by a pretreatment process (e.g., roasting, pressure oxidation, nitric acid treatment, Caro's acid treatment, bacterial oxidation, microwave calcination) and then recovered by alkaline cyanidation from the pretreated materials. Generally, gold-bearing sulphidic-arsenopyritic materials are concentrated and separated from the bulk of the ore by flotation prior to employment of a pretreatment process.

Currently, Belmoral Mines Limited, located in Val d'Or, Quebec is producing gold bearing flotation concentrate containing pyrite and arsenopyrite and assaying 2.41 oz gold per tonne of concentrate.

Approximately 95% of the gold is recovered by alkaline cyanidation of a finely ground (75% -400 mesh) concentrate with long retention times* which sometimes go as high as (168 hour)². In terms of gold recovery, this concentrate is not considered to be refractory but with such a long retention time either it is somewhat refractory or optimum leach conditions are not maintained.

CANMET believed that the leaching conditions could be adequately tailored to obtain 95% or more gold extraction within a shorter retention time (e.g., 48 hours). Belmoral Mines Limited, leaching the concentrate without any preaeration, required much longer retention times.

Generally, preaeration can maintain reasonable oxidation conditions in the leach slurry for efficient cyanidation of gold for free milling gold ores or concentrates. However, preaeration is really important when sulphides, arsenides or tellurides are present in the concentrate even when gold is not encapsulated in these minerals. Furthermore, the presence of Pb^{+2} in leach slurry is recommended to prevent oxidation of cyanide to thiocyanate (CNS)(eq. 2 & 3).



CANMET's initial approach in investigating the leaching time was to conduct conventional cyanidation tests on the Belmoral concentrate under mild preoxidation conditions (i.e., preaeration by using air or oxygen preferably in the presence of some $Pb(NO_3)_2$). This report presents the results of cyanide leach tests performed on the Belmoral concentrate.

* Currently, Belmoral Mill is maintaining retention time in the range of 68 - 72 hours (provided by R. Vachon, mill superintendent, January 1988); however almost a year ago it was 168 hours².

GENERAL PROCEDURE

The screen analysis of the as-received concentrate from Belmoral Mines Limited showed that 83% of the concentrate passed 270 mesh screen (53 μ m). Table 1 gives the chemical analysis of the as-received concentrate.

Table 1 - Chemical analysis of the concentrate

Elements	wt %	Elements	wt %
Au	2.41 oz/t	As	0.60
Ag	0.48 oz/t	S	18.90
Cu	0.49	SiO ₂	32.2
Zn	0.03	Ca	3.90
Sb	0.01	Mg	1.60
Fe	19.70	Al	4.70

All the leaches were conducted in reaction kettles equipped with a mechanical stirrer, oxygen or air sparger, temperature control probe and electrodes for the measurement of the pH and EMF of the leach slurries. The reaction kettle was charged with a known quantity of the concentrate and a calculated volume of alkaline water of pH 10.6-10.8 in order to obtain the desired initial pulp density. The pH of the leach slurry was maintained in the range of 10.6-10.8 for the duration of leaching by adding an aqueous solution of NaOH as necessary.

The leach slurries were sparged with oxygen or air for two hours in the presence of 20-30 mg Pb(NO₃)₂. At the end of preaeration or preoxygenation, a known quantity of NaCN was added at intervals to the leach slurry over a period of 12 hours. All leaches were conducted at 22°-24°C with minimum 24 hours of cyanidation.

At the end of the leaching time, the leach liquor was separated by filtration and the filtercake was washed once by repulping with water at pH 10.5 and finally twice by water displacement. Filtrates (leach liquor, repulp liquor and wash liquor) and the dried residues were chemically analyzed.

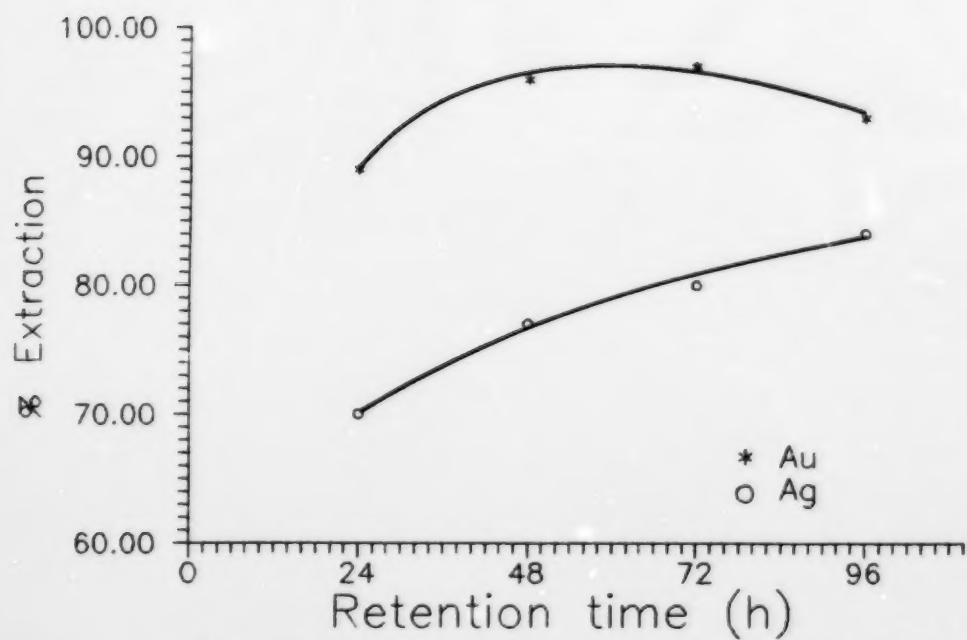
RESULTS AND DISCUSSIONS

Alkaline cyanide leaching with no preaeration

A series of alkaline cyanide leach tests were conducted on the Belmoral concentrate in order to study the extraction behaviour of gold and silver. To this end all the tests were conducted at the conditions currently applied in the Belmoral Mill, Val d'Or (i.e., NaCN: 6.0 kg/t, 22°C, 50% solids in the leach slurry, and no preaeration) but with different retention times. Table 2 and Figure 1 show the leach data and the extraction profiles of gold and silver.

Table 2 - Alkaline cyanide leaching with no preaeration
(22°C, pH 10.6, 50% solids)

NaCN initial conc. kg/t	NaCN Consumption kg/t (%)	NaOH Consumption kg/t	Ret. Time (h)	Extraction (wt %)	
				Au	Ag
6.0	2.4(40)	2.1	24	89	70
"	3.0(50)	"	48	96	77
"	3.1(52)	"	72	97	80
"	3.2(53)	2.8	96	93	84



(6.0 kg.NaCN/t , 22°C , pH 10.6 , 50 % solids)

FIG.1 Leaching as a function of retention time with no preaeration.

The data in Table 2 are indicative that after 24 hours of leaching, gold extraction was only 89%; however, the percent of gold extraction increased steadily up to 72 hours where the extraction reached the highest level (97%). As the leaching time was further prolonged to 96 hours, gold extraction actually decreased to 93%.

Unlike gold, the extraction of silver increased steadily and its highest percent extraction, 82%, appeared after 96 hours of leaching - the longest residence time applied in this test. Figure 1 shows the trend of gold and silver extractions with retention time.

It was further noticed that after 72 hours retention time the pH of the leach slurry dropped below 10 and was adjusted to 10.6 by adding NaOH. Evidently these leach results (Table 2) confirmed that 97% gold extraction could be obtained without preoxidation but with a long retention time (72 hours). The same percent of gold extraction could be obtained within 24 hours of leaching with preoxidation of the leach slurry (Table 7).

It is further evident in Table 2 that the percent silver extraction increased with increase in retention time. This observation indicates that the precipitation of silver as $\text{Ag}(\text{CNS})_2$ or Ag_2S is much less likely the case in the absence of any preoxygenation.

Leaching as a function of preaeration time

Generally preaeration oxidizes some of the cyanocides (e.g., arsenides, sulphides or tellurides) and accelerates the kinetics of gold cyanidation by maintaining favourable oxidation conditions in the leach slurry. To optimize preaeration time for maximum cyanidation of gold, a series of leach tests were conducted with varying preaeration times but at constant parameters of NaCN (6.0 kg/t), temperature (22°C), pH (10.6), pulp density (50% solids) and retention time (24 hours). Table 3 and Figure 2 show the leach results and the extraction profiles of gold and silver.

Table 3 - Leaching as a function of preaeration time
(50% solids, pH 10.6, 24 h, 22°C,)

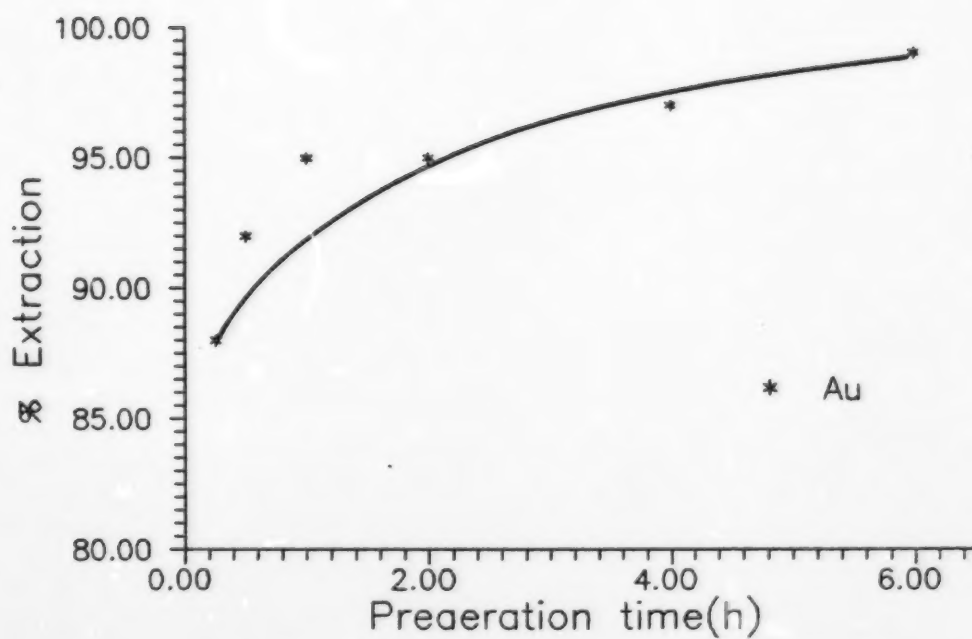
NaCN conc. kg/t	NaCN Consumption kg/t (%)	NaOH Consumption kg/t	Preaeration Time (h)	Extraction (wt %)	
				Au	Ag
6.0	2.4(40)	1.0	0.25	88	-
"	2.5(42)	1.4	0.5	92	-
"	3.1(52)	1.6	1.0	95	-
"	3.20(53)	2.0	2.0	95	-
"	3.6(60)	2.1	4.0	97	-
"	3.65(61)	2.0	6.0	99	-

* Extraction data were calculated from solution assays; silver assays were not available at the time of writing this report.

The leach data in Table 3 clearly demonstrate that gold extraction improved steadily with the increase in preaeration time. This improvement became obvious after 0.5 hour of preaeration when gold extraction reached 92%. The highest percent gold extraction (99%) took place after 6 hours of preaeration which was the maximum preaeration time applied in this series of leachings. The increase in gold extraction with an increase in presentation time is graphically shown in Figure 2.

Cyanide consumption increased with an increase in preaeration time (Table 3). This high cyanide consumption is obviously due to its oxidation into cyanate and/or thiocyanate and complexation with various metals ions (e.g., Fe, Cu, Ni, etc.) as evidence by an increase in the concentration of copper in leach liquors with an increase in preaeration time.

Finally these leach data lead to the conclusion that gold extractions in the range of 95-99% could be obtained with 1-6 hours of preaeration followed by 24 hours of alkaline cyanidation.



(6.0 kg.NaCN/t , 22°C , pH 10.6 , 50 % solids)
FIG.2;Leaching as a function of preaeration time.

Leaching as a function of NaCN-concentration

Stoichiometrically, one tonne of the concentrate requires 51.0 g NaCN to dissolve all the gold and silver. However, because of the presence of cyanide consumers such as Cu, Zn, Fe, S, As, Ca, Mg, etc., the sodium cyanide requirement is much higher. Therefore, to determine the optimum NaCN concentration for maximum gold extraction a series of leaches were conducted on the concentrate with varying concentrations of NaCN. The retention time, pH, pulp density, temperature and preoxygenation conditions were maintained constant for these tests. Table 4 shows the leach conditions and the extraction data for gold and silver.

Table 4 - Au and Ag extractions as a function of NaCN (2 h pre-oxygenation, 24 h cyanidation, 30% solids, pH 10.6; 22°C)

NaCN added (kg/t)	NaCN Consumption kg/t (%)	NaOH Consumption (kg/t)	Extraction (wt %)	
			Au	Ag
2.5	1.26(=50)	2.0	89	75
6.0	3.20(53)	"	95	77
10.0	5.40(54)	"	95	69
12.5	6.63(53)	"	96	59

It is evident in Table 4 that the highest gold extraction (96%) occurred in the leaching tests conducted with 12.5 kg NaCN/t, but 95% gold extractions took place with 6.0 kg NaCN/t and 10.0 kg NaCN/t respectively. In fact all the extraction data were very close and may be considered to be the same if the precision limit ($\pm 3\%$) of gold determination by fire assay is taken into consideration. Figure 3 shows the trend of extractions of gold and silver with the variation of NaCN concentration.

Currently, Belmoral Mines Limited are conducting leaching operations with approximately 6.0 kg NaCN/tonne of concentrate and getting 95-96% gold extraction but with retention times which sometimes extend up to 168 hours². The test data of Table 4 obviously indicate that essentially the same percent of gold extraction could be obtained with the same concentration of sodium cyanide (i.e., 6.0 kg/t) but with only 24 hours retention time provided the leach slurry is preoxygenated with air or oxygen.

Unlike gold, the silver extractions decreased with an increase of NaCN concentration. In fact the highest silver extraction (77%) occurred in the leach test conducted with 6.0 kg NaCN/t, the second lowest sodium cyanide concentration applied in this series of leach tests (Table 4). This decreasing trend in silver extraction is not precisely understood; however, it may be due to precipitation of silver as $\text{Ag}(\text{CNS})_2$. The formation of thiocyanate (CNS) is quite favourable because of high sulphur concentration (=19%) in the concentrate.

These test results lead to the conclusion that 94-96% gold extractions could be obtained at much lower retention times by maintaining NaCN concentration in the range of 6.0-12.5 kg/tonne concentrate. Furthermore, the consumption of sodium cyanide was found to be in the range of 50-54% irrespective of the initial concentrations used.

Leaching as a function of retention time

Typical gold ore contains 5-30 ppm gold along with various cyanocides such as Fe, Cu, Ni, Zn, S, As, usually in much higher concentration than gold. The kinetics of gold cyanidation in the alkaline medium is quite slow. Consequently long cyanidation time (i.e., retention time) is needed for maximum extraction of gold from ore or concentrate. Retention time has a considerable effect on the economics of gold recovery from ores or concentrates.

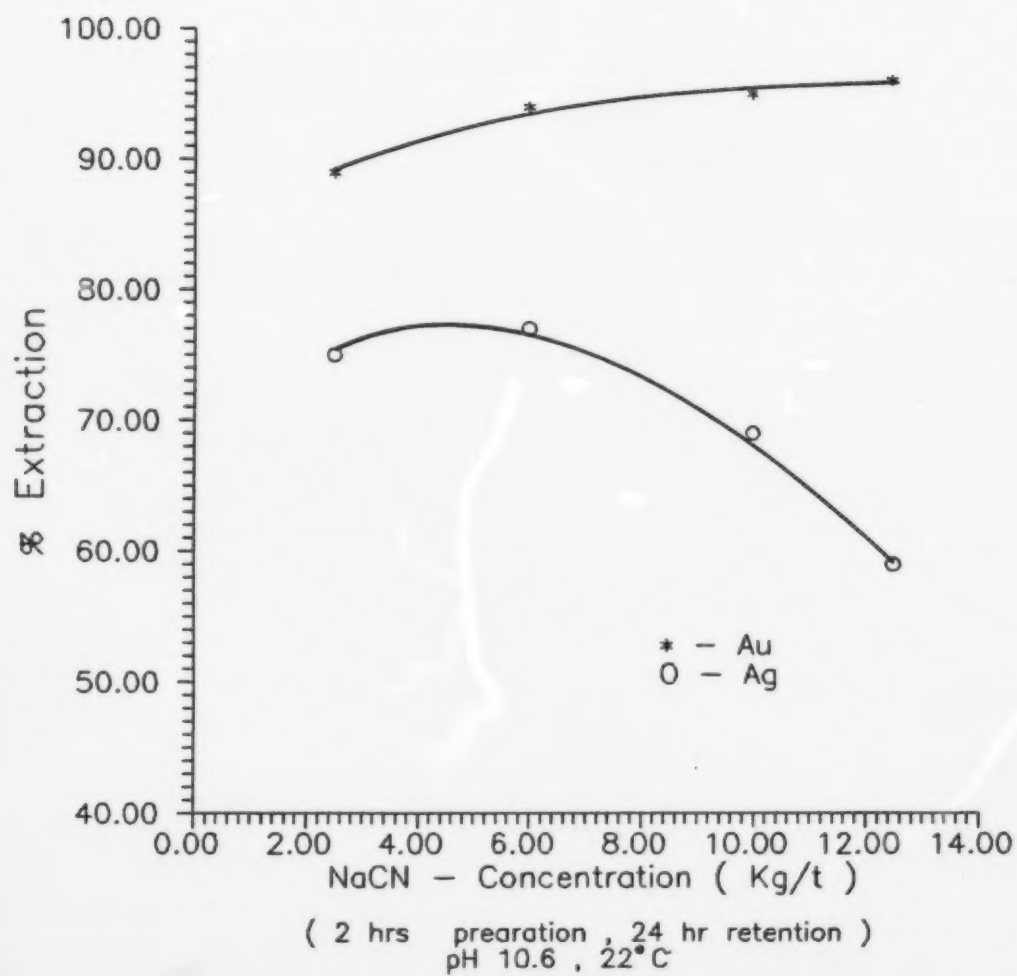


FIG.3, extraction as a function of NaCN concentration

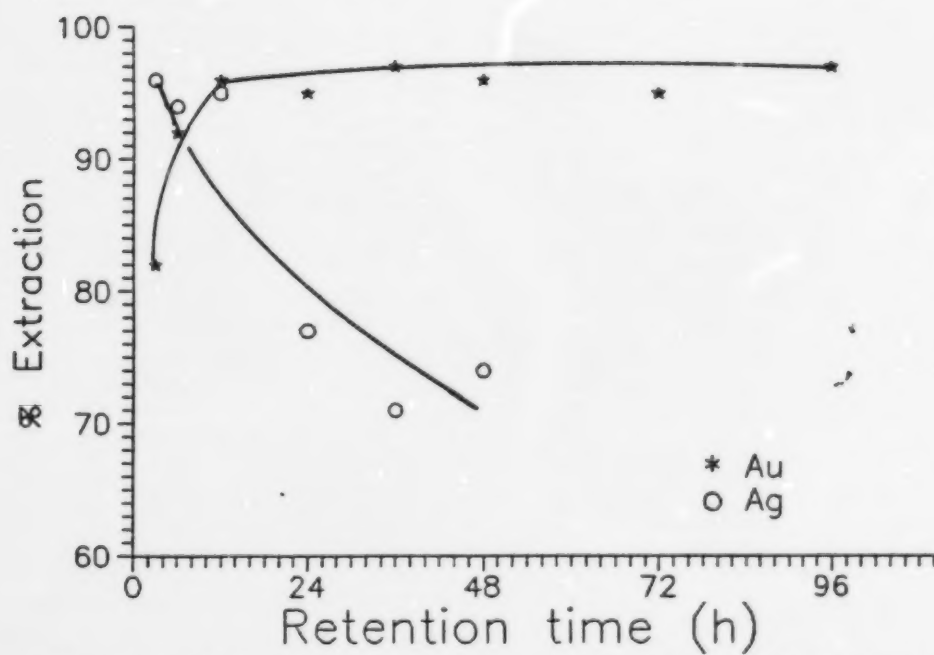
In view of these facts, it became essential to determine the most suitable retention time for maximum extraction of gold from the Belmoral concentrate. A series of leach tests were conducted with NaCN (6.0 kg/t), 22°C, 50% solids, pH 10.6 and 2 hours preaeration but with varying retention times. Table 5 and Figure 4 show the leach data and the extraction profiles of gold and silver.

The extraction data in Table 5 demonstrate that gold extraction increased with retention time and maximum extraction (97%) took place after 36 hours of leaching. However, even 12 hours retention yielded 96% gold extraction. In fact the percent gold extraction remained in the range of 95-97% from 12-96 hours retention time. These data lead to the conclusion that 95-97% gold extraction could be obtained by maintaining retention times in the range of 12-36 hours.

Table 5 - Au and Ag extractions as function of retention time
(50% solids, 2 h preaeration, pH 10.6, 22°C)

NaCN conc. kg/t	NaCN Consumption kg/t (%)	NaOH Consumption kg/t	Retention Time (h)	Extraction (wt %)	
				Au	Ag
6.0	1.26(21)	0.65	3	82	96
"	1.31(22)	1.50	6	92	94
"	1.86(31)	1.76	12	96	95
"	3.20(53)	1.85	24	95	77
"	3.3(55)	1.9	36	97	71
"	3.9(65)	2.0	48	96	74
"	4.6(77)	2.1	72	95	-
"	5.16(86)	2.0	96	97	-

* Extraction data by solution assay



(6.0 kg.NaCN/t , 22°C , pH 10.6 , 50 % solids , 2.0 hrs. preaeration)

FIG.4;Leaching as a function of retention time.

Unlike gold, maximum silver extraction (96%) took place after only 3 hours of leaching which was the shortest retention time applied in this series of tests. However silver extractions decreased steadily with the increase in retention time (Table 5)*.

The data in Table 5 further show that cyanide consumption increased with retention time. In fact 86% cyanide was consumed during 96 hours of leaching. Chemical assays of the leach liquors indicate that the concentration of iron and copper increased with retention time. Therefore, cyanide consumption due to complexation with these metals increased with longer retention time. Furthermore, excessive cyanide losses due to oxidation is also a strong possibility with long retention time.

The extraction profiles in Figure 4 show that silver extraction declined rapidly with the increase in retention time whereas gold extraction remained constant at 96% from 24-96 hours of retention.

Leaching as a function of pulp density

The solid to liquid ratio of the leach slurry is an important economic factor. High solid to liquid ratio of a leach slurry not only results in a leach liquor with high concentration of metal values but also generates less volume of effluent which is more easily and efficiently managed. As well, soluble losses would be less from a small volume leach liquor.

Because of these factors a series of tests were conducted with varying pulp densities and Table 6 shows the results. The percent gold extraction is not affected by the change of solid content in the leach slurry, and in fact, gold extraction remained high (95-96%) for 20%, 30%, 40% and 50% solids in the leach slurry.

* All extraction values were calculated from assays of the leach liquors because at the time of writing this report gold and silver assays of the leach residues were not available. Therefore no mass balance was possible.

Table 6 - Au and Ag extractions as a function of pulp density
(2 h preoxygenation, 24 h retention, pH 10.6, 22°C)

Pulp density (% solids)	NaCN (kg/t) added	NaCN Consumption kg/t (%)	NaOH Consumption (kg/t)	Extraction (wt %)	
				Au	Ag
20	10.0	5.5(55)	2.0	95	75
30	"	5.4(54)	"	95	69
40	"	5.2(52)	"	96	63
50	"	5.3(53)	"	96	60

Unlike gold, the extractions of silver were adversely affected with the increase of solids in the leach slurries especially above 30%. The highest percent silver extraction (75%) occurred from leach slurry with 30% solids. These data lead to the conclusion that slurry with 50% solids would be the most suitable pulp density for maximum extraction of gold.

Leaching as a function of oxidant

The formation of $\text{Au}(\text{CN})_2^-$ complex cannot take place without the oxidation of gold (Au^0). As cyanide anion is easily oxidizable, a mild oxidation condition should be maintained in the leach slurry. Generally, the presence of molecular oxygen either as gaseous oxygen or air in the leach slurry can maintain suitable oxidation conditions for gold without much oxidation of cyanide.

The maintenance of mild oxidation conditions (e.g., ≈ 150 mV) in the leach slurry with a strong oxidant is a fairly delicate task. To this end a series of leach tests were conducted on slurries pretreated with various oxidants such as H_2O_2 , $\text{Pb}(\text{NO}_3)_2$, ozone and air for 2 hours at pH 10.6. During this pretreatment operation oxidation potentials of the leach slurry were maintained in the range of 150 to 200 mV by controlled addition of the oxidant. However, as sodium cyanide was added to these slurries, oxidation

potentials reached -120 mV to -160 mV which were really favourable for the cyanidation of gold under alkaline condition¹.

The data in Table 7 indicate that the percent of gold and silver extractions were 97-98% and 82-83% for all the oxidants except air which yielded only 95% and 77% extractions for gold and silver. As it appears now H_2O_2 , oxone ($KHSO_5$, K_2SO_8 , $KHSO_4$) ozone, $Pb(NO_3)_2$ and Pb_2O_4 are all much better oxidants than air but cyanide consumptions were much higher (71-80%) with these oxidants than with air (44%) (Table 7).

These leach results indicate that 95-98% gold extraction could be obtained by the conventional cyanidation process within 24 hours of retention provided the leach slurries were preoxidized with a chemical oxidant or molecular oxygen such as air or oxygen.

Of course air is much cheaper than any of these chemical oxidants; however the latter provide 2-3% more gold extraction. At today's price of gold (US \$450./oz) the application of any of these chemical oxidant could be more profitable than the application of air.

Table 7 - Au and Ag extraction as a function of oxidant
(30% solids, pH 10.6, 24 h cyanidation, 22°C,
2 h pre-oxidation)

Oxidant			NaCN		NaOH Consump- tion (kg/t)	Extraction (wt %)	
Consumption (kg/t conc.)	cost/t conc. (US \$)	initial conc. (kg/t)	Consumption kg/t (%)	Au		Ag	
Oxone	5.0	8.05	7.0	5.14(73)	2.5	98	83
Pb(NO ₃) ₂	5.0	3.58	"	5.37(77)	3.5	98	82
Pb ₂ O ₄	5.84	5.84	"	5.0 (71)	2.0	97	82
H ₂ O ₂ (50V%)	25L	24.14	"	5.14(73)	2.5	97	82
ozone	6.6	-	"	5.6 (80)	2.5	97	82
Air	-	-	"	3.09(44)	2.5	95	77

CONCLUSIONS AND RECOMMENDATIONS

1. Test results show that gold in the Belmoral concentrate is not truly refractory in nature.
2. At least 95% or higher gold extraction could be obtained within 24 hours of cyanidation of the leach slurry pre-oxidized with air, oxygen, ozone, H_2O_2 , oxone, $Pb(NO_3)_2$ or Pb_3O_4 .
3. 95-97% gold extraction could be obtained by maintaining the leach conditions at 2-6 hour of preaeration, 22°C, 50% solids, 6.0 kg NaCN/t, and 24-36 hours retention time.
4. 96-97% gold extraction could be obtained without pre-oxidation of the leach slurry but only after 48-72 hours retention time.
5. Pilot-scale tests should be conducted on the pre-oxidized leach slurry in order to confirm the above test results.

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